Biomechanics contribute to plantar fasciitis treatment

Plantar fasciitis is a common occupational and sport-related repetitive strain injury. Approximately two million people in the U.S. are treated annually for the condition.[1-4] The chief initial complaint is typically a sharp pain in the inner aspect of the heel and arch of the foot with the first few steps in the morning or after long periods of nonweight-bearing. After walking 10 to 12 steps, the plantar fascia usually stretches and the pain gradually diminishes. However, symptoms may resurface as throbbing, a dull ache, or a fatiguelike sensation in the medial arch of the foot after prolonged periods of standing, especially on unyielding cement surfaces.[5-8]

The plantar fascia is a thick, fibrous, relatively inelastic sheet of connective tissue originating at the medial heel. It then passes over the superficial musculature of the foot and inserts onto the base of each toe (Figures 1A, 1B). The plantar fascia is the main stabilizer of the medial longitudinal arch of the foot against ground reaction forces and is instrumental in reconfiguring the foot into a rigid platform before toe-off.[4,9,10] Under normal conditions, the plantar fascia performs this function appropriately without incurring injury.

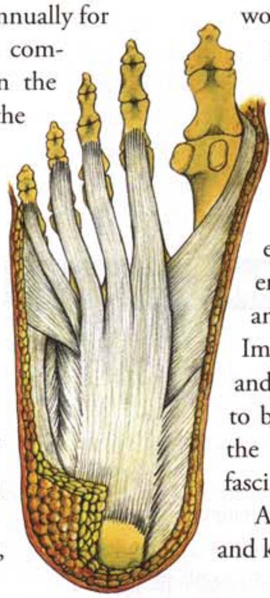


Figure 1. The plantar fascia originates at the medial heel and passes over the superficial musculature of the foot to insert onto the base of each toe.

Some risk factors for plantar fasciitis include faulty mechanics of the foot due to structural abnormalities, age-related degenerative changes, excess weight, training errors, and occupations involving prolonged standing. Those falling into this category include teachers, construction workers, cooks, nurses, military personnel, and athletes training for long distance running events.[7,8,11-14] In the presence of these risk factors, excessive tensile forces may cause microtears in the plantar fascia. Repetitive trauma to the plantar fascia exceeding the tissue's ability to recover may lead to degenerative changes and an increased risk of injury.[5,15,16] Implementing a conservative treatment and preventive protocol has been shown to be effective in resolving or reducing the symptoms associated with plantar fasciitis.[17,18]

An understanding of the anatomy and kinematics of the foot and ankle, the static and dynamic function of the plantar fascia during ambulation, and the contributing risk factors associated with plantar fasciitis aid in developing a proper treatment and preventive protocol for this condition.

Many factors go into developing a preventive protocol and proper care for this condition.

Anatomy of the plantar fascia

The foot and ankle can be divided into the rearfoot, midfoot, and forefoot. The rearfoot consists of four bones: the distal aspects of the tibia and fibula (leg bones), the calcaneus (heel bone), and the talus. The midfoot consists of five bones: the cuboid, the navicular, and three cuneiforms. The forefoot consists of 19 bones:

five metatarsal bones and 14 phalanges. The plantar fascia originates from the medial calcaneal tuberosity and divides into medial, central, and lateral bands that attach to the superior surface of the abductor hallucis, flexor digitorum brevis, and abductor digiti minimi muscles, respectively. The fascia then splits into five slips that cross the metatarsophalangeal joints and insert onto the phalanges of the digits.[1,8,19,20]

The foot has a visible medial longitudinal arch (MLA) that aids in distributing the force attributed to weight-bearing. The structure of the foot's MLA resembles two rods: a rear rod consisting of the calcaneus and talus, and an anterior rod consisting of the navicular, three cuneiforms, and the first three metatarsals. These rods are connected at their bases by the plantar fascia. When force is applied to the apex of the MLA, the arch depresses, the two rods separate, and tension is distributed throughout the plantar fascia (Figures 2A, 2B).[8,21] The main ligaments that aid in supporting the MLA are the long and short plantar ligaments and the calcaneonavicular ligament (spring ligament). During static stance, the MLA is supported by the plantar fascia, the ligaments, and the osseous architecture of the foot.[1,8,20] During late ambulation, the plantar fascia assumes a dynamic role in reconfiguring both the MLA and the rearfoot in preparation for toe-off.[22,23]

Foot and ankle biomechanics during ambulation

Gait can be separated into the stance phase and the swing phase. During the stance phase, the foot contacts and adapts to the ground surface. During the swing phase, the swing leg accelerates forward and prepares for ground contact. The stance phase consists of four subphases: initial contact, loading response, midstance, and terminal stance. During initial contact, the heel contacts the ground surface. The loading response occurs immediately after initial contact, ending when the contralateral foot lifts off of the ground surface. Midstance starts when the contralateral foot lifts off of the ground surface. The contralateral leg is now in swing phase. The midstance phase ends as tension on the gastrocnemius, soleus, and Achilles tendon (triceps surae) of the stance leg causes the heel to lift. Terminal stance phase begins when the heel lifts and ends when the swing leg contacts the ground.[19,20,24] The plantar fascia and extrinsic and intrinsic musculature of the foot play an active role in guiding the foot as it transitions from initial contact to toe-off. Efficient function of the plantar fascia and musculature of the foot depends on the configuration of the rearfoot and midfoot articulations during the different subphases of gait.[8,25,26]

The rearfoot comprises the talocrural and the subtalar joints. The talocrural joint (ankle mortise) consists of the articulation of the distal aspect of the tibia and fibula with the trochlea of the talus. It facilitates two primary movements: dorsiflexion, pulling the toes up and back toward the tibia, and plantar flexion, pointing the toes downward.[8,19,27,28]

The subtalar joint (STJ) consists of the articulation of the undersurface of the talus with the calcaneus. Movement of the subtalar joint is pivotal in transforming the foot from a rigid lever during initial ground contact to a mobile shock absorber during loading response and early midstance, and back into a rigid lever as the foot prepares for toe-off. The two primary movements that occur at the STJ are pronation and supination. Pronation of the STJ normally occurs during loading response and into early midstance. In STJ pronation, the calcaneus turns outward (everts); the talus drops downward distally and adducts toward the midline; and the talocrural joint dorsiflexes. During initial contact, the STJ is normally supinated. It pronates from loading response to early midstance and then resupinates later in midstance and into terminal stance. In STJ supination, the calcaneus turns inward (inverts); the talus moves upward proximally and abducts away from the midline; and the talocrural joint plantar-flexes. Freedom of movement in the midfoot depends on the position of the STJ.[8,19,20]

The two main articulations of the midfoot are the talonavicular joint and the calcaneocuboid joint. The midfoot revolves around two joint axes: the longitudinal midtarsal joint angle (LMJA) and the oblique midtarsal joint angle (OMJA). Movement of the midfoot around the LMJA consists of inversion (supination around the LMJA) or

STRUCTURAL ABNORMALITIES AS RISK FACTORS FOR PLANTAR FASCIITIS

Condition	Contribution to plantar fasciitis
Ankle equinus	May lead to untimely pronation of the rearfoot and midfoot articulations, placing an increased strain on the plantar fascia and other structures of the foot that are attempting to restore the MLA and resupinate the STJ before toe-off.[8,13,19,20,21,26,30]
Forefoot varus	May lead to untimely pronation of the rearfoot and midfoot articulations, placing an increased strain on the plantar fascia and other structures of the foot that are attempting to restore the MLA and resupinate the STJ before toe-off.[8,13,19,20,21,26,30]
Rearfoot varus	May lead to rapid and excessive pronation of the STJ shortly after initial contact and into midstance, placing an increased load on the plantar fascia, ligaments, and musculature of the foot that are attempting to decelerate and limit pronation.[1,3,7,8,13,19,20,26]
Pes plano valgus	May lead to rapid and excessive pronation of the STJ shortly after initial contact and into midstance, placing an increased load on the plantar fascia, ligaments, and musculature of the foot that are attempting to decelerate and limit pronation.[1,3,7,8,13,19,20,26]
Pes cavus	With pes cavus, each foot strikes the ground approximately 10,000 to 15,000 times per day.[19] Limited pronation of the STJ from loading response to early midstance may limit the pes cavus foot from effectively absorbing ground reactive forces, predisposing a person to plantar fasciitis.[8,19,20,26]

eversion (pronation around the LMJA). Movement of the midfoot around the OMJA consists of dorsiflexion and abduction (pronation around the OMJA), and plantar flexion and adduction (supination around the OMJA).

STJ pronation during loading response and into early midstance causes the talonavicular joint to diverge and move distally to the calcaneocuboid joint. This reconfiguration unlocks the midfoot, allowing it to pronate around the OMJA. Pronation of the midfoot around the OMJA will stretch the plantar fascia slightly as the MLA is depressed, transforming the foot from a rigid lever into a mobile adaptor that is better equipped to absorb ground reaction forces. Shortly after early midstance, the STJ starts to resupinate and should resupinate back to neutral before terminal stance. STJ resupination causes the talonavicular joint to move proximally to the calcaneonavicular joint, superimposing these joints and limiting midfoot and forefoot ranges of motion. STJ resupination during midstance locks the lateral column of the foot, including the calcaneocuboid joint, allowing the muscles and fascia of the leg and foot to function more efficiently in guiding the foot into toe-off.[8,19,20]

The peroneus longus and the plantar fascia are actively involved in preparing the foot for toe-off. The tendon of the peroneus longus muscle passes over the outer, plantar aspect of the calcaneocuboid joint and attaches to the undersurface of the base of the first metatarsal. During late midstance, the calcaneocuboid joint functions as a pulley for the tendon of the peroneus longus. This allows the peroneus longus tendon to stabilize the base of the first metatarsal and aid in transferring body weight medially over digits one through three. The stability of the calcaneocuboid joint pulley system depends on the STJ resupinating during midstance. Later, during terminal stance, the metatarsophalangeal joint of the first digit should dorsiflex to approximately 65°, causing the distal aspect of the plantar fascia to wrap around the metatarsophalangeal joint. These coordinated movements that occur during terminal stance have been termed a windlass mechanism.[8,19,20] During this motion, tension on the distal aspect of the plantar fascia is transmitted to its proximal attachment on the medial aspect of the heel, causing the calcaneus to invert and the medial arch to rise as the forefoot pulls back toward the rearfoot.[1,21,23,25]

Studies have demonstrated that when 33% or more of the plantar fascia is surgically released, the medial arch decreases in height and the plantar fascia loses its ability to invert the calcaneus.[21,23,29] During late stance the dynamic action of the peroneus longus and the plantar fascia prepares the foot for an energy-efficient, high-gear toe-off that occurs in a horizontal line over the metatarsophalangeal joints of digits one through three. Inability of the STJ to resupinate to neutral before heel lift places an increased load on the plantar fascia and peroneus longus as they attempt to stabilize the foot for toe-off. This may predispose the plantar fascia to injury and also result in a less efficient, low-gear toe-off that occurs in an oblique line over the metatarsophalangeal joints of digits three, four, and five.[8]

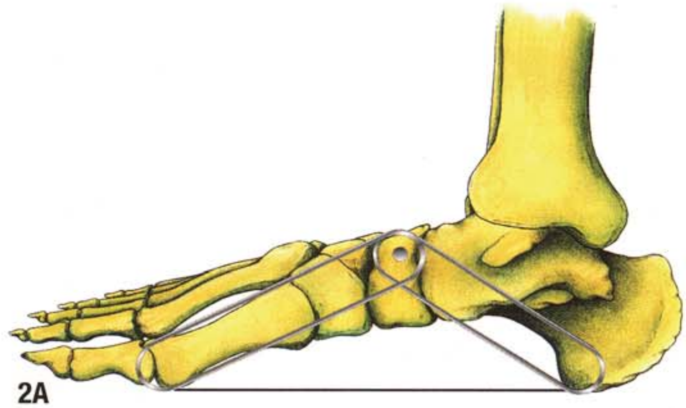
Other muscles that help stabilize the MLA and resupinate the foot include the abductor hallucis, flexor digitorum brevis, flexor digitorum longus, flexor hallucis longus, and tibialis posterior. The abductor hallucis and flexor digitorum brevis aid in restoring the MLA to its arched position and stabilizing the foot before toe-off. The flexor digitorum longus, flexor hallucis longus, and the tibialis posterior have tendinous attachment sites near the MLA. The former two muscles are active in resisting pronation from midstance to toe-off, and the tibialis posterior decelerates pronation from loading response to early midstance.[8,19,20]

Under normal circumstances, the structures of the foot and leg can absorb forces without incurring injury.

Under normal circumstances, the plantar fascia, plantar ligaments, osseous architecture, and extrinsic and intrinsic muscles of the foot and leg are able to absorb ground reaction forces without incurring injury. However, structural abnormalities may lead to faulty biomechanics of the rearfoot and midfoot. These abnormalities may cause excessive and rapid pronation of the STJ during loading response and into early midstance, or ill-timed pronation that continues into terminal stance. This may lead to an increased strain on the plantar fascia and other supporting structures of the foot, predisposing a person to developing plantar fasciitis. Structural abnormalities associated with excess, prolonged, or ill-timed pronation may include ankle equinus, rearfoot varus, forefoot varus, pes plano valgus, and pes cavus (see table, page 40).[1,2,21,28,30]

Other associated risk factors

Training errors contribute to most overuse injuries associated with running. Properly progressed training programs allow the supporting structures of the lower extremities to adapt to increased stresses. Inappropriately increasing the intensity, duration, and frequency of training runs, as well as incorporating hills on the



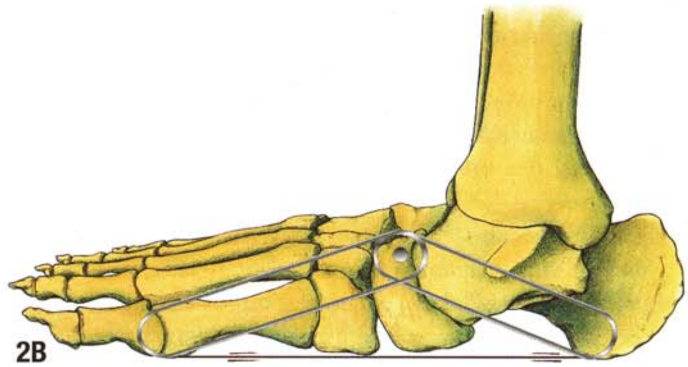


Figure 2. A: The medial longitudinal arch helps distribute the forces of weight-bearing along the foot. Its structure resembles two rods, one at the rearfoot (calcaneus and talus) and one at the midfoot (navicular, cuneiforms, first three metatarsals), connected at the top of the arch by a screw. The plantar fascia resembles a tie rod connecting the rods at their base. B: When gravity or pressure is applied to the top of the arch, the rods separate, the arch depresses, and the tie rod is stretched.

training routes too soon, may overload the supporting structures of the lower extremity, eventually leading to injury.[11,30,31]

Excess weight, age-related degenerative changes, and occupations requiring prolonged standing or ambulation contribute to the risk of plantar fasciitis.[1,3,5,11,30,32] Ground reaction forces acting on the plantar fascia and other supporting structures of the foot can reach 1.2 times body weight with walking, and 2.5 to three times body weight with running.[1,11,25] An injured recreational runner may gain weight if he or she fails to cross train and/or follow proper nutritional guidelines during periods of inactivity. Deconditioned, heavier runners may be predisposed to injury if they progress their training program inappropriately. Obese, sedentary individuals are also predisposed to plantar fasciitis. Studies have indicated an association between plantar fasciitis and those whose body mass index is 30 kg/m^2 or higher.[28,30]

Based on clinical experience, occupations that require prolonged standing on unyielding surfaces predispose the plantar fascia and other supporting structures of the MLA to repetitive tensile ground reaction forces.[13,14,32] Age-related degenerative changes to the plantar fascia and to the fat pad of the heel may predispose older people to injury by reducing the shock absorption capabilities of the foot and the ability of the plantar fascia to dissipate tensile forces.[10,11]

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This is part I of a two-part article. Next month, part II will look at various treatment options for plantar fasciitis.

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Focus:
Gait Rehabilitation Technology

The study, science, and application of gait rehabilitation technology is a growing, evolving field. No longer constrained by traditional terminology, gait technology incorporates force plates, devices, three-dimensional analysis, biomechanics, and multidisciplinary collaboration.

In this section, Josh Dubin completes his series on plantar fasciitis with a focus on treatment and prevention strategies. Ian Engelman considers how to best help patients with drop foot, using both devices and technology.

—Anthony R. Edwards

Treatment of plantar fasciitis targets several fronts

by Josh Dubin, DC, CSCS

Plantar fasciitis is a term used to denote inflammation of the plantar fascia. However, recent studies indicate that plantar fasciitis may instead be a noninflammatory degenerative process. Sonographic studies have revealed a correlation between marked (4 mm or greater) degenerative thickening of the plantar fascia and plantar fasciitis. The normal thickness of the plantar fascia averages approximately 2 mm. Based on these findings, plantar fasciitis may more aptly be termed plantar fasciosis.[1-11]

Babcock et al surmised several mechanisms that may cause plantar fasciitis pain: Repeated trauma or chronic pressure from a thickened plantar fascia may irritate pain fibers; chronic pressure of thickened fascia against digital vessels may cause ischemic pain; the effect of local pain neurotransmitters/chemicals, such as substance P and glutamate, may be enhanced; and inflammation may cause a secondary increase in nociceptor sensitivity.[12]

A practitioner can discover risk factors for and diagnose plantar fasciitis by obtaining a detailed history and conducting a physical examination. A history should include initial onset of injury; current symptoms; occupation; recent weight gain; if in training, progression of the frequency, intensity, and duration of weekly runs; whether training routes incorporated hills; age of running

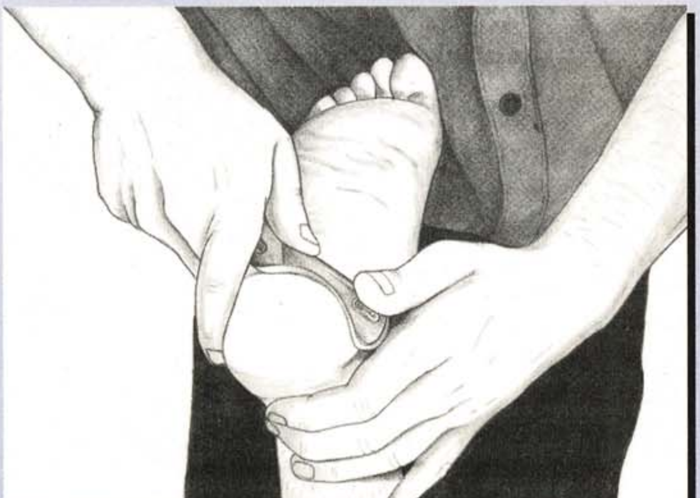

FIGURE 1. Demonstration of active release technique using the Graston tool on the medial calcaneal tubercle, in the beginning position (left) and ending position (right).

FIGURE 2. Demonstration of self myofascial release in the beginning position (left) and ending position (right).

shoes; and training goals.

Palpation may reveal tenderness over the medial calcaneal tuberosity and the medial longitudinal arch (MLA). These findings are exacerbated by maintaining digital pressure over the tender aspect of the MLA and then recreating the windlass mechanism (see, "Biomechanics contribute to plantar fasciitis treatment," March, page 39) by dorsiflexing the big toe to approximately 65°.[13]

Practitioner observation of the MLA of the barefoot weight-bearing patient may reveal a pes planus or pes cavus foot structure. A pes plano valgus foot may have callus formation over the second, third, and fourth metatarsophalangeal joints (MTPs) due to ill-timed pronation and a low-gear toe-off.

Reference lines should be drawn on the central aspect of the lower leg and the heel. With the patient prone, the subtalar joint (STJ) neutral position can be found by palpating the front of the talus with one hand and inverting and everting the rearfoot with the other hand. The STJ neutral angle can be measured with the arms of the goniometer positioned over the heel and leg bisection lines.

Inversion of the heel line, compared with the leg line, indicates rearfoot varus. Goniometer measurements are repeated with the patient standing on an elevated box. The weight-bearing measurement is compared with the STJ neutral measurement to evaluate for excessive pronation of the STJ in compensation for rearfoot varus or pes planus valgus, or for the limited pronation common in pes cavus rigidus. The STJ should pronate approximately 4° as the foot adapts to the ground terrain.[14] Range of motion of the talocrural joint should be conducted with the patient prone, the STJ held in the neutral position, and the leg fully extended. If the talocrural joint is restricted in dorsiflexion, measurements should be repeated with the leg flexed to differentiate between gastrocnemius and soleus musculature restrictions.

Forefoot varus measurements can be conducted with the patient prone and the rearfoot placed in STJ neutral. One straight edge of the goniometer is lined up across the MTPs and the other edge of the goniometer is placed perpendicular to the calcaneal bisection line.[14-16]

Radiographic examination or a bone scan may aid in ruling out differential diagnoses of calcaneal stress fracture, plantar fascia rupture, osteomyelitis, or Ewing's sarcoma. Studies indicate that calcaneal spurs are coincidental radiographic findings and are not relevant.[5,14,15,17]

Treating plantar fasciitis

Conservative treatment for plantar fasciitis should focus on decreasing pain, promoting healing, restoring range of motion and strength, correcting training errors, limiting biomechanical deviations caused by structural abnormalities, and maximizing good nutrition.[18] In my experience and based on a review of the literature the following treatment protocol is suggested:

- Manual adjustments to the ankle and foot to free up joint motion of the talocrural, subtalar, and midtarsal joint articulations;[10,11] and
- Deep tissue procedures, such as the Graston Technique (manual therapy that employs specially designed devices) and Active Release Technique (a patented manual therapy technique), to break up scar tissue and restore soft tissue motion.

I have found the myofascial technique using the Graston tool to be particularly helpful to break up adhesions at the origin of the plantar fascia on the medial calcaneal tubercle (Figure 1). Considerable clinical evidence supports the effectiveness of deep tissue procedures in treating strain/sprain injuries.[19-21] Myofascial techniques have been shown to stimulate fibroblast proliferation, leading to collagen synthesis that may promote healing of plantar fasciitis by replacing degenerated tissue with a stronger and more functional tissue.[1,22]

A home exercise program for myofascial release therapy can be taught to the patient. If the plantar fasciitis is in the right foot, the seated patient will cross the right leg over the left knee. With the right hand he or she will then grab the bases of the first, second, and third proximal phalanges and shorten the plantar fascia by flexing the toes at the MTPs. The left hand will apply digital pressure over the medial or central band of the plantar fascia. The patient will then extend the toes at the MTPs with the right hand while applying a distal-to-proximal traction with the left hand[23] (Figure 2). This maneuver can be repeated as necessary. The patient may also be taught how to roll a golf ball, laundry ball with nubs, or frozen plastic bottle under the MLA to stimulate the plantar fascia.

A strength training program for the extrinsic and intrinsic musculature of the foot should be implemented. Standing and seated calf raises strengthen the gastrocnemius, the soleus, and the intrinsic musculature of the foot. Towel gripping exercises with the toes may be another alternative in strengthening the intrinsic musculature on the bottom the foot. The tibialis anterior and extensor musculature of the foot aid in decelerating foot slap; these muscles can be strengthened with cable-resisted exercises or a dorsiflexion-assisted resistive device (DARD). Cable-resisted eversion exercises of the foot strengthen the peroneal musculature.[3,15,24,25]

Triceps surae stretching with the knee extended and bent can be done on a slant board, with a pro-stretch device, or on a flat floor. The self-myofascial release technique can also stretch the plantar fascia. Stretching of the triceps surae and plantar fascia have been shown to improve range of motion of the talocrural joint in dorsiflexion and to help in treating plantar fasciitis.[3,23,24]

A prefabricated night splint should incorporate approximately 5° of dorsiflexion of the talocrural joint and extension of the first digit. The splint passively stretches the fascia overnight and is helpful in alleviating morning heel pain caused by shortening of the fascia.[2,15,23,26] However, except for committed athletes, compliance with the night splint generally has been poor because it is bulky.[27]

A heel lift of one-quarter to three-quarters of an inch can be used temporarily to limit compensatory pronation caused by ankle equinus. As range of motion of the talocrural joint improves with therapy, the heel lifts can eventually be removed.[14,24,26]

Shoes and training

Running shoes should be changed every 300 to 500 miles. A sneaker loses approximately 50% of its ability to absorb ground reaction forces after that.[3,24,28]

Patients should be educated and encouraged to purchase the proper running shoe. A pes cavus foot structure may benefit from a cushioned sneaker; the liner can be removed and replaced with a cushioned liner. The rearfoot varus, pes planus valgus, and forefoot varus foot structure may benefit from a motion control sneaker.[29]

When appropriate, arch supports may be useful. A semirigid orthosis with a medial arch support no higher than 5/8-inch can help limit excess pronation.[6,14,16,24,26,30,31] Low-Dye taping of the foot has been shown to be effective in limiting pronation.[11,32,33]

Runners also need recommendations for appropriate training limits. For marathon runners, an initial training base of four miles at 65% to 75% of maximum heart rate should be established. Later, a progressive training schedule should be followed that allows the supporting structures of the foot to adapt so they can withstand increasing stress loads. Long training runs, usually done on weekends, should be limited to a pace that requires 65% to 75% of maximum heart rate to improve aerobic capacity.

During the week, a shorter four to eight-mile interval run at 85% to 90% of maximum heart rate is recommended to improve anaerobic capacity. Hill training should be added gradually because of the increased load placed on the lower extremities. The average marathon training schedule consists of three shorter runs during the week, and one longer run on the weekend. Total mileage should not be increased by more than 10% per week.[24,34,35]

Runner patients may also consider modifying their training with swimming, bicycling, and the elliptical machine.[1,15,24]

A viscoelastic heel cup or small cushioned doughnut can be placed over the medial calcaneal tubercle to reduce ground reaction forces acting on the proximal aspect of the plantar fascia.[26]

Adjustments to the everyday environment of patients with plantar fasciitis may also help relieve some of their pain. For example, a cushioned mat can be placed over a hard working surface, reducing ground reaction forces for professionals who stand for prolonged time periods over a fixed spot.

Other opportunities to help reduce or relieve some of the pain include nutritional advice, modalities, and drugs. A dietitian can calculate burn rate from daily exercise and develop an appropriate daily meal plan for healthy weight loss or maintenance. Ultrasound and electric muscle stimulation combination therapy can help restore normal muscle tone, aid in the healing process, and reduce pain.[11,36] Iontophoresis with dexamethasone is also a useful modality to decrease inflammation.[37]

Inflammation can be reduced by taking nonsteroidal anti-inflammatory drugs, per prescription, and applying a cold pack to the MLA for 20 minutes on, one hour off, repeated throughout the day.

Histological findings in plantar fasciitis have indicated degenerative changes with no inflammatory precursors.[3] The healing potential of NSAIDs, ice therapy, and iontophoresis for the treatment of plantar fasciitis, therefore, may be limited.

A short leg walking cast worn for approximately six weeks may limit the ground reaction tensile forces acting on the fascia, thereby limiting repetitive strain and promoting healing.[26]

Cortisone injections or surgical management may need to be considered if conservative measures are not successful in alleviating or allowing the patient to comfortably manage symptoms. Corticosteroid injections are useful in relieving pain due to inflammatory changes. However, they should be administered judiciously because multiple injections may cause a plantar fascia rupture.[2,3,18]

Conclusion

Plantar fasciitis is one of the most common causes of inferior heel pain. Structural abnormalities, overuse, weakness, excess weight, and training errors all contribute to risk of this condition. Repetitive, excessive loads placed on the plantar fascia may lead to degenerative changes that decrease its ability to absorb ground reaction forces, and to reapproximate the MLA and resupinate the STJ in preparation for toe-off. In many cases, conservative care has been found to be successful in alleviating or controlling symptoms related to plantar fasciitis. If conservative care is not effective, a cortisone injection may be useful in decreasing pain symptoms. In recalcitrant cases of plantar fasciitis, endoscopic conservative surgery is a viable option.

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